Lessons Learned for Safe and Sustainable Lunar Exploration: The Case of KPLO Operations

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- KPLO’s Journey to the Moon
- Operational Challenges and Solutions
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# Introduction to KPLO Spacecraft

<table>
<thead>
<tr>
<th>Item</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>( \leq 678 \text{ kg} )</td>
</tr>
<tr>
<td>Bus Power @ EOL</td>
<td>Average 760 Watt, (2-wing, 1-axis S/A)</td>
</tr>
<tr>
<td>Main Bus Voltage</td>
<td>26.4 ~32.8V unregulated</td>
</tr>
<tr>
<td>Mission Life</td>
<td>4 Months (Transfer-orbit) + 12 Months (Mission-orbit, include commissioning a month)</td>
</tr>
<tr>
<td>Lunar Transfer Trajectory</td>
<td>Ballistic Lunar Transfer(BLT) / Week Stability Boundary(WSB)</td>
</tr>
<tr>
<td>Mission Orbit</td>
<td>Altitude : 100 ( \pm ) 30km, Mean Inclination : 90( \pm ) 0.25deg</td>
</tr>
</tbody>
</table>
| Propulsion System                 | Monopropellant System
OMT : 30N Thruster (4EA)
ACT : 4.45N Thruster (8EA)         |
| Communication                     | S-band(Uplink) : 0.5Kbps, 1.0Kbps
S-band(Downlink) : 1.024Kbps, 16.384Kbps
X-Band(Downlink) : 8.5Mbps @HGA    |
Introduction to KPLO Mission

- **KPLO Magnetometer (KMAG)**
  - Kyung Hee University
  - Magnetic strength of lunar environment

- **KPLO Gamma Ray Spectrometer (KGRS)**
  - Korea Institute of Geoscience and Mineral Resources
  - Spatial distribution of major elements (Chemical Composition)

- **Delay Tolerant Network Experiment Payload (DTNPE)**
  - Electronics and Telecommunications Research Institute
  - Interplanetary internet communication technique (Demonstration)

- **ShadowCam (SHC)**
  - Arizona State University / NASA
  - Investigation of permanent shadow regions

- **Wide-Angle Polarimetric Camera (PolCam)**
  - Korea Astronomy & Space Science Institute
  - Polarimetric image and titanium map of Moon

- **Lunar Terrain Imager (LUTI)**
  - Korea Aerospace Research Institute
  - High-resolution lunar surface image (Korean Lunar Lander)

- **KPLO Gamma Ray Spectrometer (KGRS)**
  - Korea Institute of Geoscience and Mineral Resources
  - Spatial distribution of major elements (Chemical Composition)
KPLO’s Journey to the Moon

WSB/BLT Trajectory
Weak Stability Boundary / Ballistic Lunar Transfer

- Flight for about 133 days before LOI
- 4 Trajectory Correction Maneuvers
- 3 Lunar Orbit Insertion Maneuvers
KPLO’s Journey to the Moon

① LV Separation (8/5)
② S/A Deployment & Sun Pointing (8/5)
③ HGA Earth Pointing (8/6)
④ TCM#1 (8/7)
⑤ TCM#3 (9/2)
⑥ TCM#5 (11/2)
⑦ TCM#6 (11/16)
⑧ LOI#1, #2, #4 (12/16, 21, 26)

'22.8.26 First Imaging by Danuri

'22.9.15~10.15 Capturing the moon orbiting the Earth for 1 month

'22.11.24 Capturing the Earth and the Moon in similar size

'23.1.6~2.4 Capturing Earth’s phase change over a month

'22.12.24 Earthrise

'22.12.31

COPUOS 2024
Operational Challenges and Solutions

- Currently, six lunar orbiters are in operation.
- Three orbiters (LRO, KPLO, CH2O) are in similar altitudes of low lunar orbit.
- We monitor collision possibilities daily through the MADCAP* Report provided by NASA JPL.
- Several missions share predicted ephemeris with JPL support.
- Collision probabilities are calculated and shared based on the predicted ephemeris of the missions.
- When collision risk between two spacecrafts increases and a Red Alarm is triggered:
  - Discussions take place.
  - Mitigation measures are developed and implemented.
- Collision risk may naturally diminish over time as orbit predictions become more accurate.
- If not resolved, a collision avoidance maneuver may be performed.

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**Spacecraft Launch Date Orbit Type Altitude Inclination Angle**

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Launch Date</th>
<th>Orbit Type</th>
<th>Altitude</th>
<th>Inclination Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARTEMIS P1</td>
<td>Feb 17, 2007</td>
<td>Equatorial Lunar Orbit</td>
<td>Periaps ~100 km, Apoapsis ~19,000 km</td>
<td>Equatorial</td>
</tr>
<tr>
<td>ARTEMIS P2</td>
<td>Feb 17, 2007</td>
<td>Equatorial Lunar Orbit</td>
<td>Periaps ~100 km, Apoapsis ~19,000 km</td>
<td>Equatorial</td>
</tr>
<tr>
<td>Lunar Reconnaissance Orbiter (LRO)</td>
<td>Jun 18, 2009</td>
<td>Polar</td>
<td>~50 km (initially circular, now elliptical)</td>
<td>90°</td>
</tr>
<tr>
<td>Chandrayaan-2 Orbiter</td>
<td>Jul 22, 2019</td>
<td>Polar</td>
<td>~100 km</td>
<td>90°</td>
</tr>
<tr>
<td>Korea Pathfinder Lunar Orbiter (KPLO)</td>
<td>Aug 4, 2022</td>
<td>Polar</td>
<td>~100 km</td>
<td>90°</td>
</tr>
<tr>
<td>CAPSTONE</td>
<td>Jun 28, 2022</td>
<td>Near-Rectilinear Halo Orbit (NRHO)</td>
<td>Varies</td>
<td>90°</td>
</tr>
</tbody>
</table>

* MADCAP: Multimission Automated Deepspace Conjunction Assessment Process (by JPL)
Collision Alert History (Red Alarm)

- From February 19, 2023, to May 7, 2024, a total of 41 Red Alarms were triggered.
- Collision risks were mitigated through 4 orbit maintenance maneuvers and 4 collision avoidance maneuvers.

<table>
<thead>
<tr>
<th>No.</th>
<th>Alert On Date</th>
<th>Alert Off Date</th>
<th>Estimated Collision Date</th>
<th>Satellite Pair</th>
<th>Avoidance Maneuver</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2023-06-02</td>
<td>2023-06-05</td>
<td>2023-06-09</td>
<td>CH2O-KPLO</td>
<td>CH2O CAM</td>
</tr>
<tr>
<td>2</td>
<td>2023-06-10</td>
<td>2023-06-19</td>
<td>2023-06-24</td>
<td>CH2O-KPLO</td>
<td>KPLO CAM#1</td>
</tr>
<tr>
<td>3</td>
<td>2023-06-28</td>
<td>2023-06-30</td>
<td>2023-07-11</td>
<td>CH2O-KPLO</td>
<td>CH2O OM#70</td>
</tr>
<tr>
<td>4</td>
<td>2023-07-08</td>
<td>2023-07-17</td>
<td>2023-07-22</td>
<td>CH2O-KPLO</td>
<td>CH2O OM#71</td>
</tr>
<tr>
<td>5</td>
<td>2023-07-14</td>
<td>2023-07-15</td>
<td>2023-07-21</td>
<td>LRO-CH2O</td>
<td>CH2O OM#71</td>
</tr>
<tr>
<td>6</td>
<td>2023-10-09</td>
<td>2023-10-11</td>
<td>2023-10-21</td>
<td>CH2O-KPLO</td>
<td>CH2O OM#72</td>
</tr>
<tr>
<td>7</td>
<td>2024-01-10</td>
<td>2024-01-16</td>
<td>2024-01-19</td>
<td>KPLO-SLM</td>
<td>KPLO CAM#2</td>
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<tr>
<td>8</td>
<td>2024-02-05</td>
<td>2024-02-13</td>
<td>2024-02-19</td>
<td>LRO-KPLO</td>
<td>KPLO CAM#3</td>
</tr>
</tbody>
</table>
Necessity of International Collaboration for Future Missions

- Since the launch of KPLO, a total of 10 lunar missions have headed to the Moon.
- It is known that approximately 30 lunar missions are planned for the next six years.
- At this point, it is time to start discussions on international cooperation regarding the increasingly crowded lunar orbit.

Data Source:
List of missions to the Moon - Wikipedia
Lessons Learned from KPLO Mission

- Collision avoidance maneuvers require fuel consumption and temporary suspension of some payload mission, which may lead to differences in opinion regarding who should carry them out.
- Due to the absence of an international protocol among all agencies for resolving collision risks, we have been coordinating solutions through discussions, including email exchanges and teleconferences.
- Sometimes, we did not have the contact information of the responsible personnel, and network security issues occasionally prevented email exchanges. However, we ultimately resolved all collision risks through collaborative discussions.
- When KPLO had options, we considered how we could contribute most effectively.
- During the time SLIM was landing, urgent conjunction discussions took place, and KPLO’s decision to perform collision avoidance maneuvers helped ensure SLIM’s safe operations.

“Your proactive approach and dedication not only ensured the safety of both spacecraft but also exemplified the spirit of cooperation and collaboration between our institutions. We deeply appreciate your commitment to safety.”

- Letter from KUNINAKA Hitoshi Director General, ISAS
Thank You For Your Attention

KPLO Korea Pathfinder Lunar Orbiter

Korea's First Lunar Exploration Mission

Korea Aerospace Research Institute